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LASER FLUORESCENCE VELOCIMETER(U) TENNESSEE UNIV SPACE
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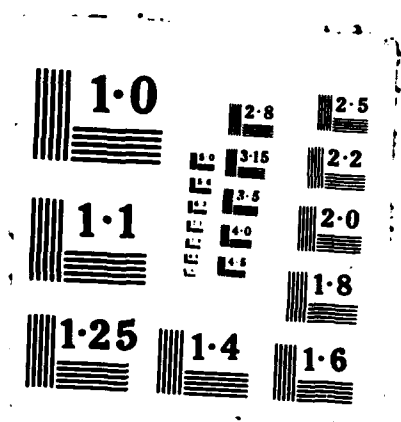
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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A new laser velocimeter was proposed which utilizes the laser induced fluorescence from atomic species imbedded in a flow, rather than scattering from particles, to determine the flow velocity. Simple theoretical models indicated that the phase shift from the space and time modulated fluorescence signal produced within a probe volume created by crossed laser beams of two different frequencies could be used to measure the fluid velocity. Experiments using static cells containing iodine verified that adequate modulation could be detected using phase-locked amplifiers. An underexpanded jet of nitrogen seeded with sodium was constructed to provide a flow-field in which a proof-of-principle experiment could be performed. This experiment was unsuccessful. A more detailed analysis of optical absorption by individual atoms in a bichromatic optical field showed that there is only a narrow range of velocities for which a single atom can absorb radiation at either of the optical frequencies. This effect greatly reduces the visibility of the fluorescence fringes within the probe volume and further limits the range of applicability of the technique.

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FINAL REPORT

DENNIS KEEFER

December 10, 1987

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UNIVERSITY OF TENNESSEE SPACE INSTITUTE
TULLAHOMA, TN 37388

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STATEMENT OF PROBLEM

Laser light scattering from particles has been used for many years to measure the velocity of the flows carrying the particles. These laser doppler velocimeter (LDV) systems are now in a mature state of technical development and a number of commercial instruments are widely used in industry and research laboratories. However, there are a number of flow regimes of interest where the measurements obtained by these instruments are not adequate. In high speed flows there are shocks where the particle velocities lag the fluid velocity by a significant amount, and in low density flows the coupling between the particles and the flow is so weak that the particles scarcely follow the flow at all. The laser fluorescence velocimeter (LFV) is an attempt to alleviate these problems by utilizing the fluorescence from the molecules that comprise the flow itself, or a seed molecule that will have a high degree of coupling to the actual flow.

The proposed measurement technique retains the basic crossed and frequency shifted laser beams used in the many of the particle scattering instruments, but utilizes the space and time modulated molecular fluorescence to determine the flow velocity. The technique does not depend on the doppler shift of the optical frequency, but utilizes the phase shift in the modulated signal that results from the finite lifetime of the excited fluorescence state. The basic theory for the method was described by Keefer [1], and showed that the fluorescence produces a continuous signal that is modulated at a fixed frequency, equal to the frequency difference in the crossed beams, and whose phase shift and visibility is a function of the flow velocity. Both theoretical and experimental research efforts were undertaken to implement this technique and to determine the range of its applicability. Initially, a simple theoretical model was developed to define critical parameters and to design an experiment that would demonstrate proof-of-principle. The experiment utilized a low density, underexpanded jet flow of nitrogen seeded with sodium to provide the required fluorescence and to minimize the effects of collisional quenching.

SUMMARY OF IMPORTANT RESULTS

Results from the basic theory and an analysis of the collecting optics indicated that adequate modulation would be obtained using an optical frequency separation of 15 MHz and a fringe spacing of 50-150 microns in the probe volume. Initial experiments using a phase-lock amplifier and a static cell containing iodine vapor at room temperature verified that adequate modulation could be detected, and the fringe structure within the probe volume was measured using the modulated signal. Based on these preliminary experimental results, an experiment was designed which used an underexpanded jet of nitrogen seeded with sodium to provide a flowfield where the phase shift produced by the flow velocity could be used to verify the basic concept. Considerable experimental difficulty was experienced with the jet source, but the system was eventually made reliable and an experiment was performed in an attempt to establish proof-of-principle. Although a sufficient fluorescence signal level was obtained, it was not possible to detect modulation from the probe volume using the phase-locked instrumentation. This result was unexpected, and various unsuccessful attempts were made to refine the experimental techniques and detect modulation.

To verify that there was adequate spatial modulation within the probe volume, a new technique was devised that used a streak camera to obtain direct images of the moving fringes in the probe volume and a Fourier domain analysis of the image to measure the fringe spacing and velocity. [2,3]

In order to detect spatial modulation from the interference between two beams of different frequency the detector must be able to respond to either frequency, as in the case of the streak camera detector. In order for an individual atom to absorb from either frequency, its absorption linewidth and velocity relative to the probe volume must span both frequencies. For sodium, the doppler half-width was much larger than the 15 MHz separation, but doppler broadening is inhomogeneous (a sum of the natural linewidths of the individual atoms over the molecular velocity distribution) and the homogeneous, natural linewidth of the sodium transition was less than the frequency of separation of the two beams. Thus, a single sodium atom may only be able to absorb photons from one or the other of the beams, depending on its velocity relative to the probe volume. Under these conditions, the fluorescence emitted from the probe volume will not exhibit the space and time modulation required for successful application of the LFV method. A detailed analysis was performed to investigate the conditions of velocity under which an atom could absorb photons from either beam. It was found that there was a narrow range of velocities in which this could occur, but the effect was to greatly reduce the visibility of the observed fluorescence modulation. [4]

We have, thus far, been unable to perform a successful proof-of-principle experiment to verify the original concept for the LFV. At this time it appears that the effects due to inhomogeneous broadening will further limit the range of applicability of the LFV technique beyond the limits already imposed by collisional quenching, and it is uncertain whether practical implementation of the method will be possible.

LIST OF PUBLICATIONS

1. Dennis Keefer, "Laser Fluorescence Velocimeter," Applied Optics, Vol. 26, pp. 91-94, Jan. 1, 1987.
2. L. M. Davis, L. M. Smith and D. R. Keefer, "An Experimental Investigation of the Probe Volume of a Laser Velocimeter." Paper 832-12, SPIE Vol. 832. SPIE's 31st Annual Symposium on Optical and Optoelectronic Applied Science and Engineering, San Diego, CA, Aug. 1987.
3. Lloyd M. Davis, "Interference Between Resolvable Wavelengths." Oral presentation at Optical Society of America Annual meeting, Rochester, NY, October 1987.
4. Wilhelmus M. Ruyten, Lloyd M. Davis, Christian Parigger, and Dennis R. Keefer, "Atomic Response to Bichromatic Crossed Beam Field," accepted for publication, American Institute of Physics proceedings, 3rd International Laser Sciences Conference, Atlantic City, NJ, November 1987.
5. Lloyd M. Davis, "Single Photon Detection of Interference Between Resolvable Wavelengths," accepted for publication in The Physical Review Letters, 1987.

LIST OF PARTICIPATING SCIENTIFIC PERSONNEL

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